Groundwater Sampling Guidelines

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EPA acknowledges Aboriginal people as the first peoples and Traditional custodians of the land and water on which we live, work and depend.
We pay respect to Aboriginal Elders, past and present.

As Victoria's environmental regulator, we pay respect to how Country has been protected and cared for by Aboriginal people over many tens of thousands of years.

We acknowledge the unique spiritual and cultural significance of land, water and all that is in the environment to Traditional Owners, and recognise their continuing connection to, and aspirations for Country.

Contents

Glossary

Annular space/Annulus	The space between a bore casing and a borehole wall
Aquifer	A geological structure or formation or an artificial land fill permeated or capable of being permeated permanently or intermittently with water
Bailer	A bailer is a hollow tube, with a check valve at the base (open bailer) or a double valve (point-source bailer), used to remove water from a bore
Background levels	The level or ranges of levels of an indicator in waters, or in aquatic ecosystems, outside the influence of any waste or contaminant containing a measurable level of that indicator
Bentonite	A hydrous aluminium silicate clay mineral available in powdered, granular or pellet form that swells when wet. It is used to provide a seal between the bore casing and borehole
Bore	Any bore, well or excavation or any artificially constructed or improved underground cavity used, or intended to be used, for any of the following purposes: (a) the interception, collection, storage or extraction of groundwater; (b) groundwater observation, or the collection of data concerning groundwater; (c) the drainage or desalination of any land; (d) in the case of a bore that does not form part of a septic tank system, the disposal of any matter below the surface of the ground; (e) the recharge of an aquifer
Bore screen	A filtering device that allows groundwater to flow freely into a bore from the adjacent formation while minimising or eliminating the entrance of sediment into the bore
Casing	Impervious, durable pipe installed temporarily or permanently into a borehole to counteract caving, advance the borehole and isolate the zone being monitored
Colloid	Particles (organic or inorganic) with diameters less than 10 mm
Contamination	A human-induced change in water quality that produces a noticeable or measurable change in its characteristics
Filter pack	Sand or gravel that is generally uniform, clean and well-rounded that is placed in the annulus of the bore (between the borehole wall and the bore screen) to prevent formation material from entering through the bore screen and to stabilise the adjacent formation
Formation	A unit of consolidated or unconsolidated geologic material characterised by a degree of lithologic homogeneity which can be charted
Groundwater	Any water occurring in or obtained from an aquifer and includes any matter dissolved or suspended in any such water. For the purpose of this guideline, and consistent with the Environment Reference Standard clause 13(2), water within a landfill cell is not considered to be groundwater

Head	Energy contained in a water mass, produced by elevation, pressure or velocity
Hydrogeology	The geological science concerned with the occurrence, distribution, quality and movement of groundwater
In situ groundwater measurements	Measurements of groundwater quality parameters collected from within a bore or aquifer
Landfill cell	A compartment within a tipping area in which waste is deposited and enclosed by cover material. Tipping area means a place within a landfill site in which waste is, has been or will be deposited
NEPM 1999	National Environment Protection (Assessment of Site Contamination) Measure, 1999 (amended 2013)
Non-aqueous phase liquid	An organic or inorganic liquid that: • is not miscible with water; and • can exist in groundwater in numerous forms; and • is commonly present as a measurable thickness (phase-separated) or sheen; and • may be identifiable analytically (in soil or groundwater) when solubility has been reached or observed to be present within the unsaturated soil, rock profile or aquifer matrix
Packer	A device placed in a bore or borehole that isolates or seals a portion of the bore, bore annulus or borehole at a specific level
Permeability	The ability of a porous or fractured medium to transmit a fluid
Representative sample	A sample that retains the chemical and physical character of the material being sampled (e.g. in situ formation water)
TCE	Trichloroethene (trichloroethylene)
TDS	Total dissolved solids
TOC	Total organic carbon
TOX	Total organic halogen
Turbidity	Cloudiness in water due to suspended, colloidal (organic and inorganic) material
VOC	Volatile organic carbon
Watertable	The surface of saturation in an unconfined aquifer at which the water pressure is equal to atmospheric pressure

1. Introduction

Groundwater is an important resource in Victoria. In addition to being a source of potable water supply, irrigation water, stock water and water for other uses, groundwater plays a significant role in maintaining base flows for many waterways and wetlands. For Traditional Owners, the relationship with waters, lands and its resources is very important to cultural vitality and resilience. The Victorian State Government recognises that groundwater has environmental values that must be achieved or maintained. These values are outlined in the Environment Reference Standard (ERS).

The *Environment Protection Act 2017* introduced the general environmental duty (GED), which requires a person to minimise risk of harm to human health and the environment from their activities. The Act also outlines duties related to pollution incidents and contaminated land.

Groundwater quality can be measured using the ERS and environmental values as benchmarks. Demonstrating that environmental values are achieved or maintained is one way to show that risks of harm to human health and the environment from contamination of groundwater have been minimised.

To maintain or achieve the environmental values of groundwater, it is important to accurately determine and report its composition. The methodology used to collect and analyse samples must be consistent with the methodology used to determine benchmarks for groundwater condition to enable comparison.

These guidelines have been developed to assist those involved in groundwater sampling to collect samples that will give an accurate measure of groundwater quality. High quality data will ensure subsequent groundwater management decisions, and comparison to the ERS, will be based on data that truly represents the groundwater quality.

1.1. Statutory framework

Victoria’s environment protection system is based on the Environment Protection Act. The Act establishes the Environment Protection Authority Victoria (EPA) and defines EPA’s powers, duties and functions. It contains several instruments to minimise pollution, waste and environmental risk. These instruments include Environment Protection Regulations, the ERS, licences, permissions, notices and environmental audits.

The definition of land in the Act includes groundwater. Where the duties in the Act require investigation or assessment of groundwater, EPA expects this guideline to be applied.

The following also contribute to the protection of groundwater quality in Victoria:

- section 31 of the Act – Duty to take action to respond to harm caused by a pollution incident (also known as the ‘duty to restore’)
- section 39 of the Act – Duty to manage contaminated land (refer also to *Assessing and controlling contaminated land risks: a proposed guide to meeting the duty to manage for those in management or control of land*, publication 1977)
- *Siting, design, operation and rehabilitation of landfills* (publication 788)
- National Environment Protection (Assessment of Site Contamination) Measure 1999.

1.2. Background and purpose of guidelines

Groundwater sampling and analysis are undertaken to:

- determine background groundwater quality and the environmental values to be maintained or achieved (ERS clauses 14, 15 and 16)
- detect any contamination and changes in groundwater quality
- determine the extent and degree of existing groundwater contamination
- evaluate the environmental performance of activities with potential to contaminate groundwater
- assess the quality of an existing or potential groundwater resource.

According to Barcelona et al (1985), significant errors in groundwater data arise from the methods used in field sampling. It is essential that groundwater sampling is undertaken in a consistent manner so that subsequent analysis provides accurate data on which to base groundwater management decisions, including critical decisions regarding the management of contaminated or potentially contaminated sites.

The key objective of this document is to foster practices that will assist with accurate and consistent determination of chemical and biological indicators of groundwater. Such practices will ensure that groundwater samples are representative of groundwater in the aquifer and will remain representative until analytical determinations or measurements are made.

These guidelines reflect current best practice and outline the critical issues that should be considered before and during groundwater sampling. They identify objectives and key measures by which the objectives can be met, focus on areas for investigation and identify relevant information and source materials.

Individual components of groundwater sampling should be assessed for their impact on analytical results, and the overall sampling technique used should be commensurate with the required sensitivity or use of the data.

The activities covered in these guidelines must be carried out by people with considerable in-field experience and professional judgement. Therefore, the guidelines do not provide detailed technical advice, and they are not intended to be a substitute for technical expertise and professional judgement.

Although these guidelines are not mandatory, they are considered best practice for groundwater sampling in Victoria and regulatory authorities may call up such a document in licences, notices, permits or environmental assessments.

1.3. Who needs these guidelines?

These guidelines are primarily intended for use by people collecting groundwater samples for chemical analysis (e.g. environmental consultants, officers of EPA and other protection agencies, authorities and site owners or occupiers). These guidelines may also be a useful reference for protection agencies that require others to take groundwater samples.

1.4. Additional guidance documents

Other relevant documents that provide information on aspects of groundwater sampling and hydrogeology include:

- *Hydrogeological assessments (groundwater quality) guidelines* (publication 668)
- *Sampling and analysis of waters, wastewaters, soils and wastes* (publication IWRG 701)
- National Environment Protection (Assessment of Site Contamination) Measure 1999 (as amended 2013) (NEPM 1999)
- Australian/New Zealand Standard (AS/NZS) 5667.1:1998 *Water Quality - Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples*
- AS/NZS 5667.11:1998 *Water quality - Sampling, Part 11: Guidance on sampling of groundwaters*.

The two EPA documents, *Hydrogeological assessments (groundwater quality) guidelines* and *Sampling and analysis of waters, wastewaters, soils and wastes*, are referred to in this guideline. We recommended that you read them in conjunction with this document.

2. Objectives of groundwater sampling

The primary objective of any groundwater (quality) sampling is to obtain groundwater samples that are representative of the groundwater in the aquifer and will remain representative until analytical determination or measurements are made.

2.1. Groundwater sampling program

A groundwater sampling program is a document describing the procedures used to collect, handle and analyse groundwater samples to achieve groundwater sampling objectives. A groundwater sampling program should be prepared before sampling, taking into account site-specific considerations (e.g. aquifer type and contaminants).

When designing a groundwater sampling program, it is essential to establish and consider the overall objectives of the monitoring program. The objectives of monitoring programs may vary. For example, they could be to monitor groundwater at a landfill or wastewater treatment plant over the long term, to establish the status of groundwater contamination at a contaminated site, or to determine background (i.e. naturally occurring), regional and ambient groundwater quality.

Groundwater sampling program

Objective

To enable sampling that will meet the objectives of the groundwater monitoring program.

Key measures

Prepare a groundwater sampling program describing the procedures used to collect, handle and analyse groundwater samples.

A groundwater sampling program should be scientifically designed and statistically valid. For further information on program design see *Hydrogeological assessments (groundwater quality) guidelines* (publication 668).

2.2. Hydrogeological assessment

Before developing a groundwater sampling program, a hydrogeological desktop study should be undertaken (as a minimum).

The desktop study will provide background and historical information to the person responsible for sampling so that they can make informed decisions about the sampling program.

The following background information must be obtained and considered as a minimum:

- **site history** – contaminants of concern and potential for contamination, including, for example, contaminant use, past practices and incident history
- **hydrogeological setting** – aquifer type and configuration, groundwater flow directions and rates, vulnerability of the aquifer system to contamination
- **previous field investigation data** – bore logs, depth and length of screened interval, depth and construction details, past water level measurements.

Hydrogeological assessment

Objective

To collect necessary background information to make informed decisions about the groundwater sampling program.

Key measures

Undertake a hydrogeological desk study in accordance with *Hydrogeological assessments (groundwater quality) guidelines* (publication 668).

This guideline does not discuss hydrogeological assessments in detail. *Hydrogeological assessments (groundwater quality) guidelines* (publication 668) should be referred to for further details.

3. Key factors that can influence groundwater samples (pre-sampling)

Drilling, construction and cleaning out (or development) of bores can affect the quality of groundwater samples extracted from them by introducing physical or chemical effects or unwanted residues.

Before sampling from a monitoring bore, the impacts of drilling, construction and development must be understood so that the appropriate sampling equipment and methodology may be selected.

3.1. Drilling

3.1.1. Drilling techniques

Drilling techniques used to construct monitoring bores must be carefully considered to reflect monitoring needs. Drilling equipment can cause smearing (e.g. rotary auger) and compaction (e.g. cable tool) of borehole walls. They may also cause geological formation materials and drilling fluids to move into different zones. These materials can block groundwater and contaminant pathways, thereby excluding contamination from the monitored material.

Developing the bore may reduce the impacts of drilling. Section 3.3 provides more information on bore development.

3.1.2. Drilling fluids

Drilling fluids are generally used during the drilling process to remove cuttings from the borehole, clean and cool the bit, reduce friction between the drill string and the sides of the borehole and hold the borehole open during the drilling operation.

Drilling fluids used include air, water and specific drilling mud formulations or native clay slurries. They can have a range of effects on groundwater quality:

Key factors that can influence groundwater samples (pre-sampling)

Objective

To drill, construct and develop groundwater monitoring bores such that there is minimal impact on the representativeness of groundwater samples.

Key measures

- The drilling technique should minimise compaction or smearing of borehole walls and transport of geological formation materials into different zones.
- Prevent cross-contamination between aquifers and between bores.
- Drilling fluids should cause minimal impact on groundwater chemistry and quality.
- Construct groundwater monitoring bores of materials that are compatible with the groundwater environment and will not leach or sorb contaminants into groundwater samples.
- After drilling and construction, develop groundwater monitoring bores and leave until bore chemistry can be demonstrated to have stabilised.
- Record the drilling method, drilling fluids used and bore development details.
- Assess groundwater monitoring bores to ensure that they will enable sampling program objectives to be met. This will require examination of monitoring bore drilling, construction, development and screen location details and physical inspection of the bore to establish its physical condition.

- Air may cause oxidation and precipitation of analytes of interest, such as dissolved metals (e.g. oxidation of ferric iron to ferrous iron). In highly permeable formations, air can have a considerable influence on the groundwater chemistry.
- Fluids contaminated with lubricants necessary for compressor operation may introduce hydrocarbons into groundwater.
- Water may dilute or flush groundwater near the bore, changing the chemistry of the groundwater.
- Water may also cause minerals to precipitate, which can block contaminant and groundwater pathways (i.e. pores and fractures).
- Drilling mud may enter the formation and seal preferential groundwater pathways.
- Clay particles within drilling mud may sorb some electrically charged contaminants (e.g. dissolved metals).
- Additives in drilling mud (e.g. surfactants and drilling detergents used to overcome drilling difficulties) may increase the potential for introduction of physical and chemical changes.

Since these effects are frequently permanent, it is important to record the drilling method, fluids used and details of bore development before sampling.

3.2. Installation

3.2.1. Casing and screen

Casing and screen materials may be incompatible with the immediate groundwater environment. Incompatible casing and screen material may result in either leaching or sorption of analytes of interest, while desorption of analytes of interest may occur if water quality changes. Diffusion of organics may also occur through polymeric casing materials.

For example, extremely acidic environments may corrode metal casing while solvents (including chlorinated hydrocarbons) may dissolve PVC casings (Parker 1992; Aller and Gardner 1995). Such reactions may cause immediate effects on water quality in the bore. Leaky casings also may allow water from different depths to migrate along the borehole and into different aquifers.

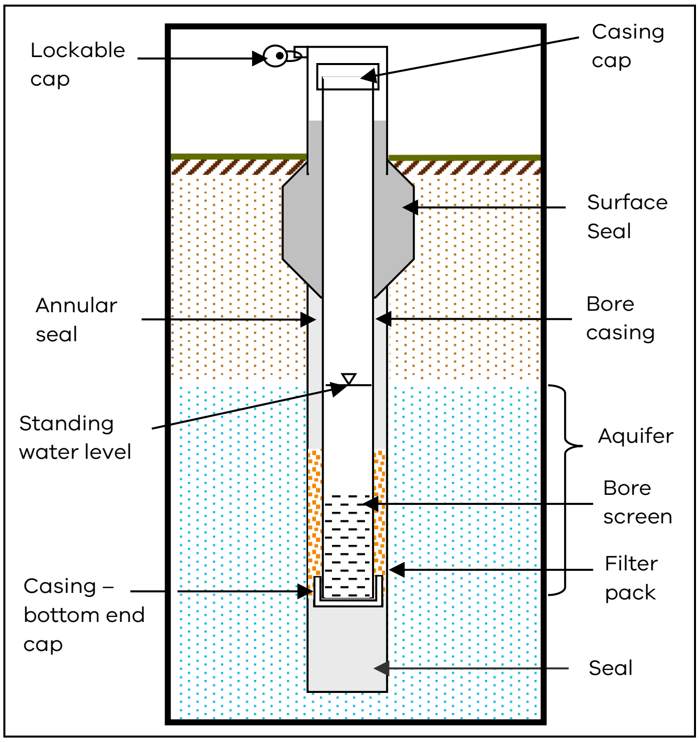

Figure 1: Groundwater monitoring bore (confined aquifer)

Inappropriately constructed casing joints may cause leakage. Solvent-bonded casing joints, which are prone to interacting with groundwater, should not be used when sampling for organics (Parker 1992; Aller and Gardner 1995).

3.2.2. Annular fill and gravel pack

Annular space is the space between the borehole walls and the casing or screen (see Figure 1). The materials used in the annular space include filter pack materials such as gravels and fine sand and seal materials such as bentonite, bentonite and cement mixtures, and cement. Any of these materials, when inappropriately used or installed, may alter the chemistry of groundwater entering the bore. Portland cement, for example, may increase pH, while bentonite may sorb dissolved metals.

3.2.3. Location of sampling point (screen depth and length)

The location and length of the screened interval of groundwater quality monitoring bores can be vital. Due to the laminar flow of groundwater, contaminated groundwater flows in discrete zones. Poorly placed screens may fail to intercept these zones. Long screens in monitoring bores are known to dilute contaminated groundwater samples due to mixing with uncontaminated groundwater; thus, the samples are not representative. Ideally, screened intervals are short and located specifically within the zone of interest. In some investigations, bores may need to be installed at more than one depth in an aquifer to access the extent of vertical groundwater flow and the distribution of contaminants with depth.

Correct location of the screened interval is especially critical when dealing with aquifers polluted with non-aqueous phase liquids (NAPLs, see Section 4.16). Representative samples for analysis of dissolved contaminants can be obtained only if the screened interval is outside the direct influence of the non-aqueous phase liquid.

These issues should be considered during a hydrogeological assessment, as discussed in Section 2.2.

3.3. Bore development

Development is the process of removing fine sand, silt and clay from the aquifer around the bore screen and breaking down drilling mud on the borehole wall. Development maximises the hydraulic connection between the bore and the formation.

Bore development generally involves actively agitating the water column in a bore then pumping water out until it is visibly clean and of a constant quality. The development process for monitoring bores should not introduce air, water or other materials into the aquifer.

In most formations, applying development techniques will result in ‘virtually sand-free or silt-free’ water to be extracted from bores (NUDLC 2020:79). However, development techniques are limited for small-diameter monitoring bores (typically of 50 mm diameter) in aquifers with low hydraulic conductivity. In such conditions, bore development may not result in samples free of turbidity. Specific techniques may need to be employed to maximise the development process.

All bores used for groundwater quality monitoring should be developed after drilling, then left for a period until bore chemistry can be demonstrated to have stabilised (anywhere between 24 hours and seven days) before samples are collected. See Section 4.5.1 for further information on stabilisation of bore chemistry.

During development, bore yield should be estimated by monitoring the rate of recovery of water in the bore after pumping. This information can be used to select suitable methods for subsequent purging and sampling.

Bores may require periodic re-development to ensure that they remain well connected to the aquifer and that representative samples can be collected. This may include cleaning out debris and siltation that has accumulated and removing biofouling that may have occurred.

3.4. Further information

The following documents provide a more detailed discussion of the above issues:

- National Uniform Drillers Licensing Committee 2020, *Minimum construction requirements for water bores in Australia*, 4th ed., NUDLC
- Driscoll FG 1986, *Groundwater and wells*, 2nd ed., Johnson Screens, St Paul, MN
- *Hydrogeological assessments (groundwater quality) guidelines* (publication 668)
- Nielsen DM (ed) 2005, *Practical handbook of environmental site characterization and ground-water monitoring*, CRC Press, Boca Raton, FL
- US EPA 1995, *Groundwater sampling - a workshop summary, Dallas, Texas, November 30 – December 2 1993*, Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, US EPA EPA/600/R-94/205, Washington, DC.

4. Groundwater sampling

4.1. Groundwater sampling personnel

Groundwater sampling requires special expertise and should be undertaken by, or in consultation with, appropriately qualified and experienced personnel (e.g. hydrogeologists). This is especially critical in situations where a site is underlain by complex hydrogeology.

Assessments of groundwater contamination require careful planning, including preparing a detailed sampling and analysis plan. The plan should include establishing data quality objectives and appropriate data quality assurance and quality control procedures. The sampling methodology should consider any contaminant-specific requirements. The data should be collected only by appropriately trained personnel and interpreted by competent professionals with qualifications and experience relevant to assessing the presence, extent and behaviour of contaminants in groundwater. A good understanding of data uncertainty and temporal and spatial data variability is important.

EPA provides guidance on engaging consultants: https://www.epa.vic.gov.au/business-and-industry/guidelines/engaging-consultants

Groundwater sampling

Objective

To ensure that all actions taken during groundwater sampling will result in the collection of groundwater samples that are representative of groundwater in the aquifer.

Key measures

- Groundwater sampling should be done by, or in consultation with, appropriately qualified and experienced personnel.
- It is highly recommended that you consult a qualified laboratory analyst before sampling.

Consulting a qualified laboratory analyst before sampling is highly recommended, especially about preserving samples collected from anaerobic environments.

4.2. Planning and preparation

Careful planning and preparation are essential elements of groundwater sampling. They may save time and reduce difficulties commonly experienced during fieldwork, and they may prevent errors from being discovered only after sampling has been completed.

Planning and preparation

Objective

To enable efficient and effective groundwater sampling by undertaking careful planning and preparation.

Key measures

Before beginning groundwater sampling, you should:

1. consider or determine the
    a. objectives of the groundwater sampling and analysis program
    b. site-specific parameters to be sampled and analysed
    c. number and frequency of samples to be collected

   d. bore details, including location, depth and diameter of bore; depth and length of screened interval; depth to groundwater (and non-aqueous phase liquid, if present), and bore drilling, installation and development details
   e. sampling protocol, including purging procedure, in-field measurements, sampling technique and equipment, filtration and preservation requirements and quality assurance/quality control (QA/QC) measures
   f. procedures for storing samples and transporting them to the laboratory
   g. National Association of Testing Authorities (NATA) accreditation status and experience of laboratories performing analyses (For all tests, the laboratories used should be accredited as well as experienced and proficient at testing the types of samples, at the concentration ranges required for the particular program.)
   h. analytical methods and limits of reporting for each method (as derived in consultation with the laboratory analyst)
   i. results from past sample events including groundwater level measurements, field measurements and purge volumes. (These may be useful as a comparison and may be read in the field if necessary. It is useful to compare field results from past sampling events while taking field readings. If readings are greatly different – for example, a 2 m difference between groundwater levels – then readings should be retaken immediately to confirm correct reading. This will save time and minimise the risk of acquiring inaccurate data)
   j. sample documentation (e.g. QA/QC forms, checklists, chain-of-custody requirements)

   Note: Items 1.b, 1.d and 1.i should be detailed in a hydrogeological assessment (see *Hydrogeological assessments (groundwater quality) guidelines*, publication 668).

2. inform the owner of the bore(s) of the proposed sampling (in situations where the bore owner is not the client or site owner)
3. schedule samples for receipt by the laboratory; discuss foreseeable problems with procedures, containers etc.; and collect sample bottles, trip blanks, preservatives and spike solutions as required
4. calibrate field meters (according to manufacturers' instructions) that don't need to be calibrated in the field, ensure all meters are working correctly and ensure correct calibration solutions are available

4.3. Quality assurance and quality control

Quality assurance and quality control ensure that the quality of the data collected during groundwater sampling is reliable and consistent with the objectives of its sampling program. The quality of data required by sampling programs will vary depending on the objectives of the program.

Groundwater sampling programs should aim to gather information of the quality necessary to support decisions about the condition of groundwater at the site. The quality requirements may vary depending on the purpose of the data and the decisions to be made. For example, some decisions may depend simply on whether a contaminant is present, while other decisions may depend on the actual concentrations of that contaminant. In the latter case, the quality requirements will be more stringent.

4.4. Quality assurance

Quality assurance (QA) is a critical component of any sampling program and must be in place and considered prior to sampling.

QA is 'all the planned and systematic activities implemented within the quality system and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality' (NEPM, 1999: Schedule B3). A quality system is defined as 'the organisational structure, procedures, process and resources needed to implement quality management' (NEPM, 1999: Schedule B3).

In terms of groundwater sampling, QA encompasses the organisational procedures, processes, resources and review necessary to ensure that the results of the sampling program accurately reflect the state of the environment at the time of sampling.

QA for groundwater sampling should consider the following (note the overlap with Section 4.2. Planning and preparation):

- objectives of sampling with regard to data quality (the level of uncertainty that is acceptable)
- project responsibilities (who will perform each task)
- protocols to be used for groundwater sampling and equipment decontamination
- sample custody
- quality control samples (e.g. which ones, how many)
- the specific analytical methods for each analyte
- storage protocols and procedures and holding times
- sample container and preservative requirements.

QA procedures and protocols need not be complex. However, they should clearly state the needs and requirements of the sampling process.

Additional information on QA is provided in the National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPM 1999).

Quality assurance

Objective

To ensure groundwater sampling is undertaken in accordance with appropriate QA/QC.

Key measures

A QA program should be in place. This should consider:

- objectives of sampling with regard to data quality
- project responsibilities
- protocols to be used for groundwater sampling
- sample filtration and preservation
- sample custody
- quality control samples
- specific analytical methods for each analyte
- storage requirements and holding times
- sample preservative requirements.

4.5. Quality control

Quality control

Objective

To assess the quality of the sampling data collected.

Key measures

A QC program should be in place. This should consider collection of:

- Blank samples including
  - Trip blanks
  - Field blanks
  - Rinsate blanks
- Duplicate samples including
  - Blind replicates
  - Split samples

Quality control (QC) assesses the quality of the sampling data collected within the framework and system provided by QA. QC 'is the operational techniques and activities used to fulfill the requirements for quality' (NEPM, 1999: Schedule B3).

'The level of QC required is that which adequately measures the effects of all possible influences upon sample integrity, accuracy and precision, and which is capable of predicting their variation with a high degree of confidence' (NEPM 1999: Schedule B2).

QC involves specific activities to assure the quality of samples, including collecting information that identifies any errors due to possible sources of cross-contamination and inconsistencies in sampling, and checking on the analytical techniques used. The reliability of data cannot be assured without the information QC provides.

For example, QA procedures and protocols may require specific QC activities such as collecting rinsate blanks and sample duplicates to ensure that the decontamination process has been successful and no cross-contamination has occurred.

4.5.1. Blanks

A blank is a portion of deionised water that is carried through all or part of the sampling process. The volume used for the blank should be the same as for the samples. Various blanks may be collected:

- **Trip blanks** are used to monitor potential cross-contamination during transport and storage. Trip blanks are clean samples of de-ionised water which are sent from the laboratory with empty containers and remain with the other samples throughout sampling without being exposed to the sampling procedures.
- **Field blanks** are used to monitor contamination during sampling. These blanks are deionised water poured into sampling containers under field conditions during sampling and should include any filtration or addition of preservatives as appropriate.
- **Rinsate blanks** (or equipment blanks) are generally taken from the final rinse of equipment after decontamination, or prior to the use of disposable sampling equipment and involve collecting deionised water that is poured over the equipment. These samples provide information ensuring that there is no cross-contamination of samples from the sampling equipment.

4.5.2. Duplicates

Duplicates are samples taken in immediate succession and subjected to the same filtering, preservation, holding and analysis methods. Duplicates are taken as a check for precision (repeatability) of sample analysis.

The number of sets of duplicate samples required depends on the required quality of the data (or the limits for the overall uncertainty of results) for decision-making purposes.

Duplicates may either be submitted to the same laboratory, as blind replicates, without any indication that they are duplicates or they may be sent to a second laboratory, as split samples, to provide a further check on the accuracy of laboratory analysis.

Duplicate samples may be compared by calculating the relative percent difference (RPD).

$$RPD = \frac{Result\ 1 - Result\ 2}{Mean\ (Result\ 1 + Result\ 2)}\ x\ 100$$

Depending on the analytes and their concentrations, varying RPDs may be acceptable.

4.6. Groundwater level measurements

Groundwater level measurements are essential to determine groundwater and contaminant flow directions and rates within aquifers. These measurements can provide information on lateral and vertical head distribution and hydraulic gradients within individual aquifers and between aquifers in layered aquifer systems. Long-term groundwater monitoring programs provide information on the temporal trends in groundwater levels (and therefore flow directions and rates) due to the effects of drought, high rainfall events and groundwater pumping.

Some important factors should be considered when planning the collection of groundwater data:

- All groundwater levels at a site should always be measured and recorded on the same day (with the date and time), to a common datum (generally mAHD – Australian Height Datum in metres), and before the bore water is disturbed by sampling.
- Groundwater levels in new bores may take some time to stabilise after installation and development (in low-permeability formations, this may require several days or longer).
- In some environments, irrigation, pumping, aquifer dewatering, and injection or tidal influences may cause rapid groundwater level fluctuations, and frequent (e.g. hourly) measurement may be required.
- In some situations, water can accumulate in bores. Taking groundwater level measurements after purging, as well as before any disturbance of bore water, may provide results that are more representative of aquifer conditions.
- Methods and instruments used to collect and record changes in groundwater levels can vary substantially depending on the design of the monitoring program and borehole construction. The more common instruments are fox whistles, electrical tapes, pressure

Groundwater level measurements

Objective

To obtain accurate and representative measurement of groundwater level.

Key measures

- Before groundwater level is measured, allow it to stabilise after bore installation and development.
- Measure groundwater level before the bore water is disturbed by sampling.
- Measure groundwater level to a common datum.
- Measure and record all groundwater levels at a site on the same day.
- Where groundwater levels fluctuate rapidly, take more-frequent measurements (e.g. hourly).

transducers and manometers or pressure gauges for flowing bores. Although many electronic methods exist, such as pressure transducers and data loggers, fox whistles remain both accurate and reliable.

4.7. Purging

Purging is the process of removing stagnant water from a bore before sampling. In some groundwater monitoring bores, where groundwater levels are above the screen, or where a bore is not in good working order (e.g. due to siltation of the screen, blockages within the bore, bores having not been purged and sampled for some time, or ingress of water from surface etc.), there is a column of stagnant water above the bore screen that remains standing in the bore between sampling rounds. Stagnant water is generally not representative of formation water because it has had extended contact with bore construction materials (e.g. casing), it is in direct contact with the atmosphere and it is subject to different chemical equilibria. Stagnant water often differs from formation water in temperature, pH, redox potential, dissolved oxygen (DO) and total dissolved solids content. Volatile organic compounds and dissolved gases in stagnant water may volatilise or effervesce within as few as two hours (Nielsen 2005).

Purging aims to enable the extraction of a sample that is representative of formation water while creating minimal disturbance to the groundwater flow regime. Although purging is necessary in many situations, purging itself may affect the chemical composition and hence representativeness of samples.

There are several different approaches to ensuring that formation water rather than stagnant water is sampled. These approaches are used in different situations and should be considered on a case-by-case basis, depending on aquifer parameters and analytes of concern. Methods include:

- removing a number of bore volumes of groundwater until chemical equilibrium is reached
- low-flow purging until chemical equilibrium is reached
- passive sampling where minimal purging is required.

Purging

Objectives

To ensure that formation water is sampled rather than stagnant water.

Key measures

- In all cases, purge and sample bores in order of least (or least likely to be) to most (or most likely to be) contaminated.
- Allow field parameters (e.g. pH, specific conductance, dissolved oxygen, redox potential, temperature and turbidity) to stabilise before samples are taken.
- Record field measurements of stabilisation criteria.
- Do not use bailers and inertial samplers for low-flow purging as they can cause repeated disturbance and mixing of bore water.
- Use consistent purging and sampling methods over time for the same bore.
- Do not dewater the screened interval in the bore.
- Ensure the rate of purging is less than the rate of pumping during development.
- Record the purging method used.
- Dispose purged groundwater appropriately.

Measures of stabilisation criteria, such as pH, dissolved oxygen (DO), electrical conductivity (EC), redox potential (Eh) and turbidity, indicate when stagnant water has been purged (Puls and Powell 1992, 1997). Where possible, these parameters should be measured using a flow-through cell.

The parameters may be considered stable when three consecutive readings (obtained several minutes apart) are:

- ± 10 per cent for dissolved oxygen
- ± 10 per cent turbidity
- ± 3 per cent for electrical conductivity (specific conductance)
- ± 0.1 for pH
- ± 10 millivolts (mV) for redox potential .

The most sensitive of these parameters are redox potential, dissolved oxygen and turbidity (Puls et al. 1992).

Where bores are in good working order, low flow sampling or passive (no purge) sampling, where used appropriately (refer Section 4.7.2 and Section 4.7.3), will provide samples that are most representative of groundwater within the aquifer.

In all cases, bores should be purged and sampled in order of least (or least likely to be) to most (or most likely to be) contaminated.

Disposal of purged water

Water purged from a well is waste according to the definition of waste in the EP Act. Waste must be disposed of to a lawful place in a manner to minimise the risks of harm to human health and the environment. In accordance with the Regulations, the disposal may require a permission (e.g. an A18 Permit is required to dispose waste to an aquifer).

4.7.1. Removing a number of bore volumes until chemical equilibrium is reached

Using this purging method, bores should be purged until all stagnant water is removed and water within the bore is representative of formation water. The rate of purging must be less than the rate of pumping during bore development.

A number of bore volumes (commonly three to five) may need to be removed from a bore before the drawn water is representative of formation water. The bore volume should be calculated to include the screened interval. The bore volume may be calculated by using the equation in Box 1.

$$Bore\ volume = casing\ volume + filter\ pack\ volume$$
$$= \frac{\pi h_2 d_2^2}{4} + n\left(\frac{\pi h_1 d_1^2}{4} - \frac{\pi h_2 d_2^2}{4}\right)$$

Where:

π = 3.14
n = porosity (0.3 for most filter pack material)
h_1 = height of water column
d_1= diameter of annulus (drilled bore hole)
h_2 = length of filter pack
d_2 = diameter of casing

Box 1: Bore volume calculation

Removing a set number of bore volumes (e.g. three to five) without measuring stabilisation criteria will not ensure that subsequent samples are representative. This method should not be used for purging. Some situations may require 10 or 20 bore volumes to be removed before parameters stabilise (Nielsen 2005). The time or purge volume required for parameter stabilisation is independent of bore depth and volumes (Puls and Barcelona 1996).

In many circumstances, this is not the preferred method of sampling groundwater. Pumping or bailing large volumes of groundwater may lead to one of the following:

- sampling water coming from a depth other than that at which the bore is screened
- groundwater some distance from the bore being introduced, which may dilute or concentrate some sampling parameters.

These outcomes can lead to order of magnitude errors in dissolved chemical constituent data (Barcelona et al. 1994). Over-pumping may cause high turbidity and erroneously high measurements of total metals levels. It could also cause damage to the filter pack (Barcelona et al. 1994). High pumping rates may also adversely affect the representativeness of volatile organic compound (VOC) sampling and analysis.

At contaminated sites, care must be taken to treat and dispose of contaminated groundwater removed during purging and sampling in such a way as to avoid occupational health and safety risks or pollution of surface water, land or uncontaminated groundwater.

Using a bailer is only recommended for sampling the surface layer of the aquifer and is not recommended where other sampling methods are available.

4.7.2. Low-flow purging until chemical equilibrium is reached

Purging large volumes of water can be impractical and hazardous, and it can adversely affect the contaminant distribution in the sub-surface (e.g. through dilution). Low-flow purging (also known as micro purging) involves minimal disturbance of the water column and aquifer and is preferable to removing a number of bore volumes. This method removes only small volumes of water, typically at rates of 0.1 to 0.5 litres per minute (L/min) (Puls and Powell 1997), at a discrete depth within the bore.

For low-flow purging, the bore should be in good working order with no signs of surface water infiltration, siltation of screens, blockages within the bore. Also, for watertable aquifers, the standing water level should be within the screened interval (where possible).

Low-flow purging relies on the concept that groundwater moves horizontally through the screened interval in a bore and that formation water does not mix with the stagnant water above the screened interval (see Figure 2).

Low-flow purging consists essentially of the following steps:

1. The pump inlet is carefully and slowly (to minimise water column disturbance) placed in the middle or slightly above the middle of the screened interval at the point where the contaminant concentration is required. Dedicated pumps are ideal for low-flow sampling. Placing the pump inlet too close to the bottom of the bore can increase entrainment of solids that have collected in the bore over time.
2. Purging begins, typically at a rate of 0.1 to 0.5 L/min, although higher rates may be possible providing the rate of purging does not cause significant drawdown in the bore. Standing water level should be measured during purging, and drawdown of the water column in the

well during purging should be minimised[1]. The volume of water purged should be several times the volume of water represented by the drawdown in the bore (see Box 2 2).

3. During purging, groundwater stabilisation parameters should be measured and recorded (see Section 4.5) to determine when they stabilise.
4. When parameters have stabilised, the sample may be collected at a rate slower or equal to purge rate.

For a typical 50 mm monitoring well, 0.1 m drawdown represents the removal of approximately 0.5 L of water from the bore.

If 5.0 L has been purged with only 0.1 m drawdown, it can be demonstrated that most of the purged water was from the aquifer. In that case, the parameter measurements taken at stabilisation are likely to be representative of aquifer conditions.

If 1.0 L has been purged with 0.1 m drawdown, then a significant portion of the purged water is due to the drawdown in the well, rather than from the aquifer. In this instance, the measurements taken at stabilisation may not be representative of aquifer conditions.

Box 2. Assessing drawdown vs purge volume

4.7.3. Passive (no-purge) sampling

Passive or no-purge sampling is the process of acquiring a sample from a bore without disturbing the stagnant water within the bore and without first purging the stagnant water from the bore.

Passive sampling techniques and devices rely heavily on groundwater continuously moving horizontally through the bore screen. Therefore, these methods are not suitable for bores in aquifers where groundwater flow is very slow (e.g. in aquifers with low hydraulic conductivity or with higher hydraulic conductivity but low hydraulic gradients). Using passive or no-purge sampling in these environments may produce samples that are not representative of groundwater in the aquifer. Thus, these methods should only be used when justified in the context of the hydrogeological setting. Where used appropriately, these methods can significantly reduce, or eliminate, the requirement for purging before collecting samples.

To use passive sampling methods, the bore should be in good working order with no signs of surface water infiltration, siltation of screens, blockages within the bore. Also, for watertable aquifers, the standing water level should be within the screened interval (where possible).

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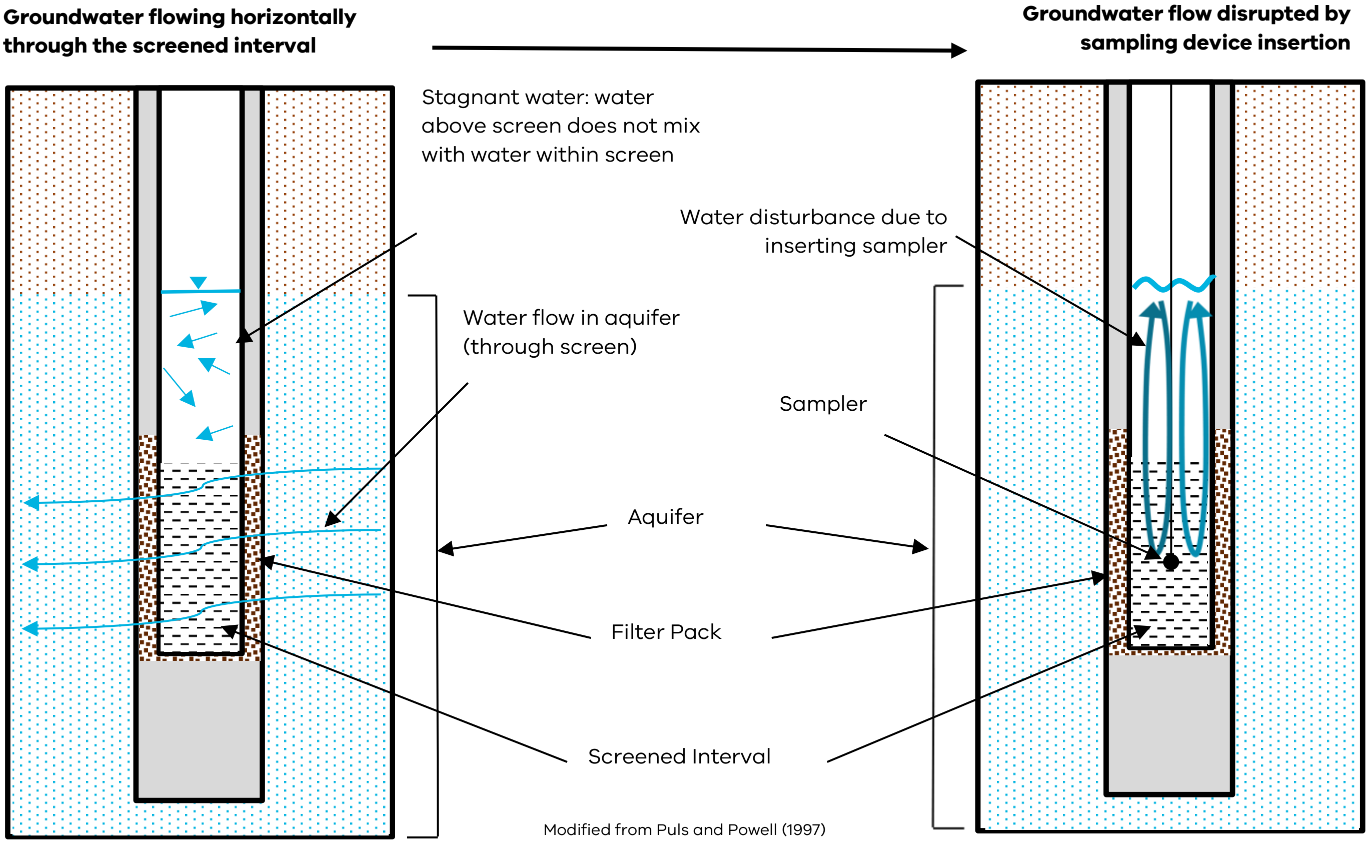
[1] Puls and Barcelona, 1996 state "*The goal is minimal drawdown (<0.1 m) during purging. This goal may be difficult to achieve under some circumstances due to geologic heterogeneities within the screened interval, and may require adjustment based on site-specific conditions and personal experience.*"

Normally, no-purge samples will provide results more similar to low-flow samples than to bore-volume purging. This is because both low-flow sampling and no-purge sampling disrupt the ambient groundwater flow regime less than bore-volume purging does.

Used properly, passive sampling techniques have the potential to provide the best contaminant concentration data (Puls and Powell 1997), however the sampler should understand that there may be limitations depending on the hydrogeological setting, type of analyte(s) being sampled for and style of the monitoring program (refer McHugh (2016) for example). The Interstate Technology and Regulatory Council (ITRC 2006) provides an overview of passive and no-purge sampling technologies that can help determine a suitable sampling methodology.



Modified from Puls and Powell (1997)

Figure 2. Groundwater flow through a bore

Low-purge sampling

For low-purge sampling, a pump is permanently installed in the bore, and the intake is placed within the screened interval and left until water in the screened interval has reached chemical equilibrium. The water column is not agitated during sampling because the sample device does not need to be inserted into the bore (see Figure 2). It is therefore possible to generate very low purge volumes (less than one bore volume according to Barcelona et al. (1994)) by pumping at a low flow rate, as the only purging required is for evacuation of the sampling device (e.g. pump body and tubing). As passive sampling relies on the sample or purge device not agitating the water column, inertial samplers and bailers cannot be used during passive sampling. It is not always necessary (or possible) to measure stabilisation parameters during passive sampling. However, it is advisable to measure these parameters the first few times a bore is sampled to enable a purge volume to be established.

Passive diffusion bags

Diffusion samplers typically consist of a low-density polyethylene bag filled with deionized water, which acts as a semipermeable membrane and is suspended in a well to passively collect groundwater samples. Diffusion samplers work on the principle of diffusion whereby chemical compounds dissolved in water move from areas of high concentration outside the sampler to the initially low concentration inside the sampler until equilibration is reached. Equilibration between the diffusion sampler and well water is critical to ensuring that a representative sample is retrieved. The time to reach equilibrium can vary and may be up to two weeks. Care needs to be taken when installing the devices to ensure that they sample the appropriate interval within the bore screen. The primary advantage of using diffusion samplers is the cost savings associated with the reduced sampling time. Because diffusion sampling does not require purging the water in the well, sampling time can be reduced by 80 per cent compared with methods that require purging.

Results of analyses of samples collected with diffusion samplers may need to be validated against analyses of samples collected by other sampling methods before diffusion sampling is applied in a field-sampling program. Passive diffusion bags may not be suitable for all contaminants of concern (USGS 2014).

No-purge samplers

No-purge samplers (e.g. Hydrasleeves™ or Snap Samplers™) collect a sample from a discrete vertical interval within the bore screen.

The sampling device should be carefully placed in the bore to the targeted interval within the bore screen. The device should be left for a suitable duration to enable the water in the bore to re-equilibrate with the formation prior to sample collection (it may not be appropriate to deploy and retrieve these samplers on the same day).

The main limitation of no-purge samplers is the limited volume of sample that can be collected during each sampling event.

4.7.4. Low hydraulic conductivity aquifers

In some low hydraulic conductivity aquifer formations, it may not be possible or practical to pump bores until field parameters stabilise, as bore recovery is slower than pump rates, including low-flow pump rates. Low hydraulic conductivity formations are generally fine grained (e.g. clay) and are naturally more susceptible to producing turbid water samples.

Collecting a representative sample from a low yielding well will be difficult regardless of the sampling technique used. The limitations and implications of using analytical data from samples collected from low yielding wells must be discussed when reporting sampling results.

The geology, bore construction and well development should be reviewed before resorting to compromised sampling techniques. Increasing the well yield may sampling require re-development, but in some cases may require re-drilling and re-installation.

The recommended procedures for purging low hydraulic conductivity bores are:

- Use low-flow purging as discussed in section 4.7.2. Purging at less than 0.1 L/min may be required. Packers *may* be useful to isolate the section being sampled.

- Use passive sampling as discussed in section 4.7.3, noting that for low yielding wells, there is unlikely to be sufficient flow through the bore for bore water to be in equilibrium with groundwater the formation.
- Removal of a percentage of the bore volume, then sampling upon recovery. Where significant drawdown in the bore is unavoidable, dewatering of the screened interval should be minimised. This may require repeated recovery of bore water during purging while leaving the pump in place within the screened interval of the bore.

Purging the bore dry is not recommended as this may expose the groundwater recovering into the well to air and other gases or floating substances, producing an unrepresentative sample.

4.8. Field measurements

Field measurement of groundwater parameters provides a rapid means of assessing certain aspects of water quality. It has the advantage of reducing the possibility of contamination or change in sample composition between collection and analysis. Careful field measurement enables representative analysis.

Field measurements are generally taken to:

- ensure that formation water is being sampled
- provide onsite measurements for water quality parameters that are sensitive to sampling and may change rapidly (e.g. temperature, pH, redox and dissolved oxygen)
- compare with laboratory measurements of these parameters to assist in the interpretation of analytical results of other parameters (e.g. check for chemical changes due to holding time, preservation and transport).

Groundwater parameters measured in the field must include pH, temperature, dissolved oxygen, redox potential and electrical conductivity and may include turbidity. Some ions, such as fluoride and sulfide, can also be determined using ion-selective electrodes, although their determination can be subject to interferences from other dissolved components (known as matrix inference).

Field measurements may be taken either in situ or after groundwater has been extracted from a bore. If groundwater is being pumped, it is recommended that a flow-through cell with probes be used for field measurements as it allows for continuous measurement and minimises sample contact with the atmosphere. Take field measurements immediately before collecting each sample.

Ensure field instruments are robust, reliable and well maintained, and that they are capable of measuring to the appropriate level of accuracy. They must be calibrated before use with fresh solutions. pH and dissolved oxygen meters need to be calibrated before every use. They can be calibrated either in the laboratory or in the field. The manufacturer’s instructions are the best guide for the use of each meter. However, meters must be calibrated according to relevant NATA publications, such as *General accreditation guidance: general equipment table* (NATA 2019).

Field measurements

Objective

To ensure accurate measurement of water quality parameters using field meters.

Key measures

- Take field measurements immediately before collecting each sample.
- Where groundwater is pumped, use a flow-through cell to take field measurements.
- Calibrate field meters according to manufacturers’ instructions and relevant NATA publications, such as *General accreditation guidance: general equipment table* (NATA 2019).
- If you are using field meters over several hours, take periodic readings of a reference solution to ensure calibration is stable.
- Record potential causes of interference in the field.

Each meter must be calibrated over an appropriate range for the samples analysed. If you are using a meter over several hours, you must take periodic readings of a reference solution to ensure the calibration is stable. If you observe excessive drift, you must discard readings taken over the period of drift.

While field meters are designed to withstand a level of harsh treatment (such as knocks, vibration and extreme temperature changes), good maintenance and calibration regimes ensure that meters produce reliable and accurate data.

Secondary parameters such as temperature, salinity, altitude and air pressure may affect some field measurements. For example, all the above parameters affect dissolved oxygen readings. If the field meter does not automatically measure and compensate for a secondary parameter, then you must measure this parameter using the appropriate equipment and compensate manually. Consult the manufacturer's instructions for correction factors.

Many factors may interfere with field measurements and cannot be compensated for. In particular, oily films, high levels of suspended solids and electrical fields may cause problems. If you are taking measurements in unusual situations, record the field conditions and consult the manufacturer's instructions to establish whether interference could occur.

Field measurements of EC can be converted to TDS and should also be compared to laboratory analysis of TDS where possible. Conductivity is measured in microsiemens per centimetre (µS/cm). Pure water cannot hold an electric charge but water that contains minerals and salt can. Therefore, conductivity is related to the amount of salt and minerals in the water. The salt amount in water is known as total dissolved solids (TDS). This is measured in parts per million (ppm), which is equivalent to milligrams per litre (mg/L) for aqueous solutions. The EC to TDS conversion factor will depend on the types of minerals and salts dissolved in the water. This conversion factor can be found in published tables. If the actual conversion factor cannot be found, then 0.67 is frequently used as an approximate conversion factor.

$$TDS = field\ electrical\ conductivity\ x\ conversion\ factor$$

The electrical conductivity measurement used in the TDS conversion should be the final reading taken immediately before sampling, when field parameters have stabilised.

4.9. Collecting samples

Groundwater samples should be collected when the solution chemistry of the groundwater purged from a bore has stabilised, as indicated by pH, dissolved oxygen, redox, EC, temperature and turbidity readings (see Section 4.7). Where a flow-through cell is used to monitor water quality parameters, it should be disconnected or bypassed during sample collection as solutions in the probes can affect sample chemistry.

Samples should be collected at a rate slower than or equal to the purging rate. Where samples are collected at a faster rate than purging, particles previously not removed during purging may be forced out of the aquifer and gravel pack and into the sample.

Sampling should use the same device previously used for purging.

4.9.1. Processes responsible for altering sample chemistry

The major processes involved in altering the chemistry of samples, and that may be directly controlled by choice of sampling device, are volatilisation, degassing, oxidation, precipitation and sorption.

Volatilisation is the loss of dissolved compounds by evaporation on contact with a gas phase. It is controlled by the vapour pressure of the solute or solvent. Compounds most susceptible to volatilisation include volatile organic compounds such as chlorinated hydrocarbons (e.g. trichloroethene, TCE) and monocyclic aromatic hydrocarbons (e.g. benzene).

Degassing is the loss of dissolved gas from solution. It can result from either an increase in temperature or a decrease in pressure. Parameters potentially affected by degassing are pH (likely to increase through loss of carbon dioxide) and pH-sensitive parameters such as heavy metals, alkalinity and ammonium (all likely to decrease). Total dissolved solids and total organic carbon are also affected and are likely to decrease in concentration due to degassing.

Precipitation is the formation of solids from constituents that were once dissolved. Precipitation can be caused by a change in conditions, such as temperature, pH or chemical concentration, or the presence of seed particles to begin the process. For example, when a groundwater sample experiences loss of carbon dioxide, a rapid change in pH can occur, causing precipitation of metals such as iron.

Sample collection

Objective

To minimise impact on representativeness of groundwater sample due to sample collection.

Key measures

- Collect groundwater samples when the solution chemistry of the groundwater removed from a bore has stabilised.
- Disconnect or bypass flow-through cell before collecting sample.
- Collect samples at a rate slower than or equal to the purging rate.
- Use the same device for sampling as previously used for purging.
- The sampling device should cause minimal physical or chemical alteration to the sample.

Oxidation is caused by the introduction of oxygen (in air) to the sample. Oxidation results in increased dissolved oxygen, pH and redox. These changes can potentially lead to decreases in concentrations of calcium ions, magnesium ions, heavy metals (particularly iron and manganese), hydrogen sulfide and ammonium. Oxidation could also cause a decrease in the concentrations of chemical oxygen demand, biological oxygen demand and total organic carbon, due to accelerated oxidation of organic constituents such as volatile fatty acids and semi-volatile organic carbon.

Sorption involves the attraction of dissolved constituents to the surface of solid particles. Any process or activity that increases suspended solids in samples can change the measured concentrations of dissolved major ions, heavy metals and hydrophobic organic compounds (e.g. organochlorinated pesticides). A loss of dissolved constituents from samples due to sorption can result when the dissolved constituents sorb onto solids in suspension before the solids are separated from the sample for laboratory analysis. Alternatively, where additional solids or colloids remain in solution or suspension (i.e. turbid samples) during analysis, increased concentrations of ions and metals may be recorded. The presence of fine-grained materials combined with low redox potential conditions may promote increased turbidity by the formation of colloids (Saar 1997).

4.9.2. Sampling devices

According to Barcelona (1995), field sampling (of groundwater) can be the most significant source of error in determining analytical results that are representative of field conditions. Error introduced during sampling is a significant issue. While very low detection limits are possible in the laboratory, they may be limited by practical considerations related to the performance of sampling devices in the field.

Appropriate devices should be selected for purging bores and collecting groundwater samples. Following these recommendations will improve the quality of groundwater samples collected:

- Use a sampling device that causes minimal physical or chemical alteration to the sample. As discussed in Section 4.9.1, it is important that the sampling device does not cause degassing, aeration, volatilisation, oxidation, sorption or precipitation through any of the following
    - the mode of transporting the sample to the surface
    - interaction with the materials of construction of the device
    - transfer of the sample to its container.

  To gain the most representative data, sampling devices should be made from inert materials such as stainless steel and Teflon. Flexible components such as tubing should be made of flexible PVC or polyethylene. However, the materials selected will depend on the sensitivity of the information required and the contaminants being assessed (e.g. per- and poly-fluoroalkyl substances (PFAS) require specific sampling equipment). Appendices A and B provide information on the adequacy of sampling devices for contaminants of concern and their potential impacts on sample quality.

- Consider using a dedicated sampling device permanently installed in the bore. This approach can reduce time (and cost) involved in set-up, sampling and decontamination. A dedicated pump also lets you use passive sampling techniques, improving the representativeness of groundwater samples.
- Ideally, use the same sampling device for purging and sampling to reduce the amount of decontamination required and to reduce turbulence in the bore.
- If you use a bailer, use cord that can be decontaminated between each bore. Do not use cotton or cloth cord.

The following important *practical* considerations must be addressed before sampling:

- the depth from which the sample is collected - the deeper the sample interval the more head the device must overcome to deliver the sample to the surface
- the ability of the bore to accommodate the sampling device - the smaller the diameter of the bore, the more limited the options
- ease of operation, cleaning and maintenance
- ease of repair – it is a distinct advantage to be able to repair the device in the field
- reliability and durability – especially where the sampling device is to be used for an extended period in groundwater environments containing chemical constituents that cause corrosion of metallic parts or degradation of synthetic materials.

The sampling device selected should be assessed for its impact on results, and the sampling technique used should be commensurate with the required sensitivity or use of the data. In general, bladder pumps are likely to cause minimal disturbance to samples during collection. They are generally the most effective sampling devices for sampling gas-sensitive analytes and VOCs (Parker 1994; Barcelona et al. 1984).

4.10. Filtration of groundwater samples

Filtration is the process of separating suspended solids from a sample by forcing it through a porous barrier (filter). Sample preservation processes may dissolve suspended solids. Filtration is undertaken to enable samples to be preserved as soon as possible after sampling without suspended solids adversely influencing the representativeness of the sample. As with other components of the sampling process, filtration is known to significantly affect the resultant analytical data. Thus, you should thoroughly consider before (and during) sampling whether filtration is needed.

Filtration of groundwater samples

Objectives

To enable samples to be preserved as soon as possible after sampling without suspended solids adversely influencing the representativeness of the sample.

Key measures

- Filter the samples when the objective of sampling is to determine truly dissolved concentrations of analytes.
- Avoid filtration where it is reasonably possible to change sampling practice to eliminate turbidity caused by purging and sampling to determine mobile concentrations of analytes.
- Do not filter samples to compensate for inadequate sampling practice.
- Where filtration is necessary, it should occur in the field, immediately after each sample has been collected and before chemical preservation. In-line filtration is recommended.
- The decision to filter or not to filter groundwater samples must be justified and reported with the resultant analytical data.

4.10.1. Effect of purging and sampling technique

Purging and sampling methodology can have a large impact on whether a sample needs to be filtered. Techniques that cause agitation of water in a bore (e.g. inertial lift pumps and bailers) are more likely to produce highly turbid samples. Increased pump rates (greater than 1 L/min) increase sample turbidity and bring larger particles into suspension (Puls et al. 1992). Samples obtained by low-flow or passive sampling are more likely to be low in turbidity. In situations in which a bore may produce turbid samples, techniques should be used that obtain the least turbid, and subsequently the most representative, samples of groundwater.

Filtration should be avoided where it is reasonably possible to change sampling practice to eliminate turbidity caused by purging and sampling. Do not filter samples to compensate for inadequate sampling practice (Barcelona et al. 1995).

4.10.2. Is filtration necessary?

In determining the need for filtration, consider the sampling objectives. *Ideally, samples should be collected so that there is no need to filter.*

Even when suitable purging and sampling techniques are used, you may need to filter groundwater samples when:

- you are sampling to determine truly dissolved concentrations of analytes
  or
- it is not possible or practical to obtain a sample with low turbidity (i.e. visually clear) due to solids suspended as a result of purging and sampling, and you are sampling to determine mobile concentrations of analytes (dissolved and colloidal) subject to sorption by suspended particles (predominantly metals and hydrophobic contaminants such as PCBs and organochlorine pesticides).

The decision to filter or not filter groundwater samples must be justified and reported with the resultant analytical data. Spatial and temporal consistency in methodology are important to ensure comparability of groundwater quality data.

4.10.3. Effects of sample filtration

Filtration may affect samples in several ways:

- Exposing the sample to air during filtration can cause metals such as iron to oxidise and precipitate. The iron precipitates may clog the filter, thereby further lowering the iron concentration in the sample. Iron precipitates may also entrain other metals (through co-precipitation), further reducing metal concentrations in the sample.
- Dissolved metals in the sample may adsorb onto the filter material.
- Suspended solids may clog filter pores.
- Small suspended solids that are naturally mobile in groundwater may be removed.
- Samples may be subject to increased handling.

Adverse effects of filtration on the sample may be minimised in the following ways:

- Exposure of the sample to air can be avoided by using an in-line filtration apparatus.
- Adsorption of metals may be reduced by rinsing the equipment with sample water before sample collection.
- Pore clogging may be reduced by increasing the ratio of filter surface area to volume of water filtered by
  - changing the filter regularly
  - increasing the filter diameter
  - using filter cartridges, which have much greater surface area
  - processing the minimum amount of water needed for analysis.

4.10.4. When you need to filter samples

When filtration is necessary, it should be done in the field, immediately after each sample has been collected and before chemical preservation. Samples can be filtered either by gravity or by applying vacuum or pump pressure. In all cases, you should only apply low pressures.

Direct, in-line filtering of samples is recommended. This is done by attaching the filter directly to a pump's discharge line or to the discharge tube of a grab sampler (e.g. bailer).

Carefully consider what pore diameter is appropriate before filtering. The most common filter size in groundwater sampling is 0.45 µm. However, this filter diameter does not achieve an accurate representation of:

- truly dissolved metal concentrations – 0.1 µm or 0.05 µm may be more appropriate (Puls and Barcelona 1989)
- concentrations of contaminants sorbed to colloids larger than 0.45 µm that are naturally mobile in groundwater (Saar 1997).

A wide range of filtration media exists, including cellulose nitrate, cellulose acetate and glass fibres. Cellulose nitrate filters are commonly used for major ions (excluding nitrates) and metals, while cellulose acetate is used for nutrients (including nitrates). Glass fibres are sometimes used as they block less frequently; however, they do not have a well-defined pore size (Murray-Darling Basin Commission 1997).

Clean filtering devices in the same way you clean sample containers, and take care not to introduce contamination in the field. Filters from the batch used in the field and the filtering device itself should be provided to the laboratory so that blank levels can be determined. Onsite (between sample) final rinses from filtration equipment should also be submitted to the laboratory as rinsate blanks for analysis.

4.10.5. When you need to filter samples, but cannot do so in the field

When field filtration is necessary but is expected to affect the representativeness of samples due to extreme field conditions, or may pose an unacceptable health or safety risk to field personnel, it may be necessary to undertake filtration in the laboratory. In such situations it will be necessary to:

1. overfill and immediately seal sample containers
2. cool the sample
3. transport the sample to the laboratory with minimum delay
4. inform the laboratory of the need to filter immediately on receipt of the sample
5. filter in the laboratory.

Consult a laboratory analyst when preservation is delayed due to not filtering in the field.

4.11. Sample containers, preservation, labelling and logging, transport and holding times

Decisions concerning the selection of sample containers, preservation procedures, labelling and logging, transportation and holding times should be made during the planning phase of any sampling program. Requirements for sample preservation, containers and holding periods for groundwater samples should be discussed with a NATA-accredited laboratory. *Sampling and analysis of waters, wastewaters, soils and wastes* (publication IWRG701) also provides guidance.

4.12. Decontamination

All equipment that either enters the bore or carries the water from the bore to the sampling container should be decontaminated before each sample is taken. Decontamination ensures that sampling equipment is clean and contains no trace of the previously sampled groundwater, which can cause erroneous analytical results (cross-contamination).

Decontamination procedures should be developed on a site-specific basis, considering the objectives of the sampling program, potential contaminants, and sampling and purging equipment.

In general, decontamination procedures include the following steps:

- Decontaminate sampling and purging equipment away from the sampling location to minimise the potential for cross-contamination.
- Use phosphate-free detergent, bleach or solvent as the decontamination solution. Choose the solution depending on the contaminants being investigated. For example, use bleach to sterilise equipment between sample points when sampling for microbiological parameters, but do not use bleach if sampling for chlorine. Similarly, some cleaning solvents are not appropriate if sampling for volatile organic compounds. Furthermore, you may need to apply other contaminant-specific methods (e.g. for PFAS).
- Wash and rinse equipment in contaminant-free water (e.g. tap water) followed by a final rinse in distilled or deionised water.
- In some cases, for example, when investigating the presence of organic contaminants, it may be necessary to rinse equipment with solvent (e.g. acetone).
- Take final rinsate (QC) samples from equipment as blanks to ensure that all contamination has been removed.
- Air dry equipment before use for sampling. Take care to ensure that exhaust from motor vehicles or compressors does not contaminate equipment.

Decontamination

Objective

To avoid cross-contamination of groundwater samples.

Key measures

- Decontaminate all groundwater sampling equipment between sampling locations.
- Decontaminate equipment away from the sampling location.
- Wash and rinse equipment with contaminant-free water followed by distilled or deionised water.
- Take final rinsate (QC) samples from equipment as blanks to ensure that all contamination has been removed.
- Air dry equipment before use for sampling.

You should make provision for disposing of contaminated wastewater or solvent from the decontamination process. It may require containment and disposal at an appropriate disposal or treatment facility.

4.13. Health and safety

Relevant risk assessments and occupational health and safety protocols must be followed when sampling groundwater. Details of these are not provided in this guide. It is assumed that the sampler will be competent in this area and that these details have been provided by the relevant employer or are available from resources such as standards for a given procedure. Any personal protective equipment (PPE) required must be used by people having adequate experience and knowledge in their use.

4.14. Documentation

For long-term monitoring programs, it is essential that samples be collected in a consistent manner so that the resultant analytical data is comparable. Thus, groundwater sampling methodology must be thoroughly documented on each sampling occasion.

Documentation

Objective

To document sufficient data during sampling to ensure that sampling practice is consistent during each subsequent sampling occasion.

Key measures

Record the following items in a logbook or sampling work plan:

- purpose of sampling
- location, description and photographs of sampling point
- detail of sampling site (well ID, well co-ordinates, elevation of casing, casing diameter, integrity of casing, casing depth, interval sampled, condition of bore)
- weather conditions during and immediately preceding sampling (e.g. has it rained in the preceding days?)
- reference to procedures for preparation of reagents or supplies that become an integral part of the sample (e.g. filters and absorbing reagents)
- identities of sampling team
- decontamination procedures
- sample method (including purging)
- standing water level
- pump rate for purging and sampling
- purged volume
- field measurements
- potential for interference with field measurements
- date and time of sample collection
- number and volume of samples taken (including any QC samples)
- field observations
- signature of the responsible personnel and date
- sample preservation including storage method
- sample transportation
- specific comments and remarks.

4.15. Reporting groundwater sampling results

Overall, the groundwater sampling report should fully describe and justify the sampling methodology chosen and state any possible impacts that the sampling methodology may have had on the quality of the sample.

Appropriately qualified and experienced professionals (e.g. hydrogeologists) should analyse and interpret the data (see Section 4.1). Guidance on data presentation is provided in *Hydrogeological assessments (groundwater quality) guidelines* (publication 668).

Reporting groundwater sampling results

Objective

To accurately and consistently report groundwater sampling details that assist in interpreting analytical results.

Key measures

Present the analytical results of groundwater sampling along with the following information:

- bore drilling, construction and development details
- purging and sampling equipment used
- purge technique (including volumes removed and stabilisation criteria)
- visual observations of the sample
- field measurements
- whether samples were filtered or unfiltered
- whether samples were filtered in the field or in the laboratory
- preservation techniques
- transport and holding times
- equipment decontamination details
- Quality control sample results and interpretation
- analytical results.

4.16. Sampling for non-aqueous phase liquids

Non-aqueous phase liquid means an organic or inorganic liquid that:

- is not miscible with water; and
- can exist in groundwater in numerous forms; and
- is commonly present as a measurable thickness (phase-separated) or sheen; and
- may be identifiable analytically (in soil or groundwater) when solubility has been reached or observed to be present within the unsaturated soil, rock profile or aquifer matrix.

NAPLs may be lighter (LNAPL) or denser (DNAPL) than groundwater, and they form discrete layers or pools within the ground (e.g. a layer of petrol situated on the watertable). When present in aquifers, NAPLs are considered an uncontrolled source of groundwater contamination that require investigation and, in most cases, clean up. The presence of NAPLs can be significant for groundwater sampling. Where light non-aqueous phase liquid is present within a bore, it is not possible to obtain a representative sample of groundwater for dissolved phase petroleum components.

Sampling of NAPLs is a specialised subject, and a detailed methodology is beyond the scope of these guidelines. However, here are some issues to consider before sampling NAPLs:

- When investigating LNAPL contamination, monitoring bores must be constructed so that the screened interval intersects the top of the watertable which is where the LNAPL is most likely to be encountered.
- When investigating DNAPL contamination, monitoring bores must be constructed so that the screened interval intersects the base of the aquifer or a low-permeability layer, where the DNAPL may be encountered.
- DNAPLs may migrate in a different direction to that of groundwater flow. This will affect positioning of bores.

Consider the following during the sampling of NAPLs:

- Sample at the interval where the NAPL is most likely to be encountered (i.e. the top of the water column in a bore when sampling LNAPL or the bottom of the bore when sampling DNAPL).
- Do not purge before measuring the thickness of, or sampling from, the NAPL layer.
- Measure LNAPL thickness with either a LNAPL–water interface probe or a weighted tape coated with a water- and LNAPL-sensitive substance to distinguish between the air–LNAPL and LNAPL–water interfaces.
- Measure DNAPL thickness with an interface probe.
- Decontaminating equipment may be quite difficult, so consider using disposable equipment.
- Use single or double check valve bailers for collecting LNAPL and double check valve bailers for collecting DNAPL collection. Peristaltic pumps may also be effective.

NAPL science remains an evolving field, and it is advisable to review the most recent resources available at the time of investigation.

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Appendix A: Sampling equipment

(Modified from Murray–Darling Basin Commission 1997, p. 11; Nielsen 1991, pp. 471–81)

Sampling equipment	Advantages	Disadvantages
Bailer A bailer is a hollow tube with a check valve at the base (open bailer) or a double valve (point-source bailer). The bailer is attached to a line and lowered into the water. The bailer is pulled up when the desired depth is reached with the weight of the water closing the check valve.	• Can be constructed from a variety of materials compatible with analytes of interest • Can be different diameter and length to suit the sampling point • No external power source required • Easy to clean, or disposable • Inexpensive and readily available	• Aeration, degassing and turbulence can occur while lowering the bailer through the water column or while transferring the sample from the bailer to the sample container. Bailers are generally not suitable for volatile and gas-sensitive analytes • Surging effect of bailers that fit tightly into a bore casing may induce fine particles from the formation to enter the bore • When used in a deep bore, prolonged sample handling may affect air-sensitive chemical constituents • It may be difficult to determine the point within the water column that the sample represents. • Lines used for the bailer can be difficult to decontaminate • Bailer check valves may fail to function properly under certain conditions (e.g. high suspended solids) • In deep bores, purging becomes time-consuming and labour-intensive • The person sampling the bore is susceptible to exposure to any contaminants in the water sample • Bailing does not supply a continuous flow of water to the surface

Sampling equipment	Advantages	Disadvantages
Inertial lift pump This pump consists of a foot valve at the end of a flexible tube which runs into the water. Initially the water column in the tube is equal to that in the well. An initial rapid upstroke lifts the water column in the tubing a distance equal to the stroke length, on the down stroke the foot valve opens allowing fresh water to enter the tube.	• Simple construction, inexpensive • Manual, gas or electric motor driven • Good for sediment-clogged bores • If dedicated, avoids cross-contamination	• For use primarily in small-diameter bores as large bores increase the possibility of tube sway • Pumping action agitates bore, introducing suspended material • Works optimally with deep installation of tubing. This may result in the bore not being properly purged • Low flow capacity
Syringe devices A syringe or similar device attached to tubing is lowered to a selected depth in the water column. Suction is applied to the tubing and the syringe, filling the syringe with water.	• Neither aeration nor degassing of the sample occurs, as the sample does not come in contact with the atmosphere • Can be made of any material • Inexpensive, highly portable and simple to operate • Can be used in small-diameter bores • Sample can be collected at various intervals • Can be used as sample container, thereby reducing the potential for cross-contamination	• Inefficient for collecting large volumes • Syringes cannot be used for purging • Sample contamination by components of ‘home made’ syringe sampling devices is possible unless fabrication materials are carefully selected • Syringes can only be used in water with a low suspended solids content as some leakage may occur around the plunger when syringes are used to sample water containing high suspended solids

Sampling equipment	Advantages	Disadvantages
Gas-drive devices Positive gas pressure applied to the surface of water within the sample chamber forces the sample to the surface through an open tube.	• Relatively portable • Readily available • Inexpensive • Some are suitable for bore development – depends on yield rate of device • Can deliver sample at a controlled, nearly continuous rate	• If air or oxygen is used as the driving gas, oxidation may occur, causing precipitation of metals and gas stripping of volatiles. CO_2 may also be driven from the sample causing a pH shift. Consequently, air-lift sampling may not be appropriate for many gas-sensitive analytes • Gas stripping of volatiles may occur • An air compressor or large compressed air tanks must be transported to deep bores, reducing portability • Excessive air pressure can rupture gas entry or discharge tubing
Suction lift pumps Suction lift pumps apply a vacuum to either the bore casing or to tubing that runs from the pump to the desired sampling depth.	• Highly portable • Readily available • Flow rate can be controlled • Inexpensive • Can be constructed for small-diameter bores • With peristaltic pumps, the pump does not come in contact with the sample – only the tubing contacts the sample	• Limited sampling depth (6–9 m) • The application of strong negative pressure (suction) causes degassing of the sample and loss of volatiles • Potential for hydrocarbon contamination of samples due to use of petrol or diesel for running the pump
Gas-operated piston pump Gas-operated piston pumps consist of one or more pistons moving inside a submerged cylinder or barrel. When gas pressure drives the piston up and down, one-way check valves direct water moved by the pistons to the surface.	• Sample is isolated from the driving gas, so no aeration of sample occurs • The pump provides a continuous sample over extended periods of time • Easy to operate • Flow rates can be controlled by varying the driving gas pressure • Can achieve pump lifts of 100 m	• The pump's valving mechanism may cause a series of pressure drops in the sample, leading to sample degassing and pH changes • Unless the pump intake is filtered, particulate matter may damage the pump's intricate valving mechanism • Not highly portable – it must be vehicle mounted

Sampling equipment	Advantages	Disadvantages
Bladder pump A flexible bladder within the device has check valves at each end. The pump is lowered into the water and gas from the ground surface is cycled between the bladder and sampler wall, forcing water to enter the bladder and be driven up the discharge line.	• Sample is isolated from the driving gas, minimising the problems of sample aeration and gas stripping • Samples collected with these devices lose very little of even the most volatile constituents (Parker 1994) • Portable, small diameter • Pumping rate of most of these pumps can be controlled to allow for both bore purging and collection of large sample volumes • Most models are capable of pump lifts greater than 60 m	• Deep sampling requires large volumes of gas and longer cycles, increasing operating time and expense and reducing portability • Check valves in some pumps may fail in water with high suspended solids content • Most pump models are expensive • Minimum rate of sample discharge of some models may be higher than ideal for sampling volatile compounds
Gear-drive electric submersible pump An electric motor rotates a set of gears which drives the sample up the discharge line.	• Constructed from inert or nearly inert materials • Wide range of diameters • Readily available • High pumping rates are possible for removing large volumes • Provides a continuous sample over extended periods	• Conventional units are unable to pump sediment-laden water without damaging pump • Smallest diameter pump is relatively expensive • No control over flow rates
Submersible centrifugal pump A submersible electrical motor drives an impeller in the pump, which creates pressure and forces the sample up a discharge line. Can also comprise an impeller rotating inside bore casing rather than pump housing.	• Small-diameter pumps can be operated at variable rates • Constructed from inert or nearly inert materials • Portable • Pumping rate of these pumps can be varied	• Does not handle viscous fluids efficiently • Conventional large-diameter submersible centrifugal pumps are subject to excessive wear in abrasive or corrosive waters

Sampling equipment	Advantages	Disadvantages
Helical-rotor pump Uses an electrically driven rotor-stator assembly that moves the water through a progression of cavities to the discharge line, forcing a water sample up the discharge line.	• Portable and relatively easy to transport • High pumping rates are possible • Constructed from inert or nearly inert material	• The flow rate cannot be controlled • High pumping rates may create turbulence, which may affect sample chemistry • Thorough cleaning and repair in the field may be difficult, as the pump is difficult to disassemble • Water with high suspended solids content can cause operational problems • The pump must be cycled on and off every 20 minutes to avoid over-heating
Passive diffusion bags Uses permeable bags filled with de-ionised water suspended in the well to allow contaminants to diffuse into the bag until equilibrium with concentrations in groundwater is reached.	• No purging • Disposable • No interference from turbidity • Easy to deploy and recover • Can join multiple samplers to obtain vertical profiles	• May not be suitable for all analytes • Samples integrate concentrations over time so may not represent point in time concentrations • Difficult to show sample is representative of aquifer • Second sampling method required to measure groundwater quality parameters • May not be suitable for low-permeability aquifers • May require separate site visits to deploy and retrieve
Discrete interval samplers Uses a sealed sampling container which is opened once it has reached the desired sampling interval and then closed prior to retrieval.	• Samples all analytes • Inexpensive • Disposable (some methods) • No purging • Sample sealed in situ (some methods) • No sample transfer required (some methods) • Can join multiple samplers to obtain vertical profiles (some methods)	• Limited sample volume • Difficult to show sample is representative of aquifer • Some assembly and disassembly required • Some decontamination required (unless disposable) • May require separate site visits to deploy and retrieve

Appendix B: Groundwater sampling device matrix

This table is provided as a general guide only. Which device is appropriate will depend on the objectives of the investigation, the performance and properties of the device, and the environmental conditions. Under certain conditions a combination of sampling devices should be considered, and some devices may not be appropriate for all parameters.

				GROUNDWATER PARAMETERS											
				INORGANIC							ORGANIC				BIOLOGICAL
	Sampling device[1]	**Minimum bore diameter (mm)[2]**	**Sample delivery rate or volume[3]**	EC	pH	Redox	Major ions	Trace metals	Nitrate fluoride	Dissolved gases	Non-volatile	Volatile	Total organic carbon (TOC)	Total organic halogen (TOX)	Coliform bacteria
Grab	Bailer (open)	13	variable	•	X	X	•	•	•	X	•	X	X	X	•
	Point-source bailer	13	variable	•	•	•	•	•	•	X	•	X	•	•	•
	Syringe	39	0.05 – 0.1 L (litres)	•	•	•	•	•	•	X	•	•	X	X	•
Positive displacement (submersible)	Gear-drive pump	51	0 – 2.3 litres per minute (Lpm)	•	•	•	•	•	•	•	•	•	•	•	X
	Bladder pump	39	0-9.Lpm	•	•	•	•	•	•	•	•	•	•	•	•
	Helical-rotor pump	52	0-5.4 Lpm	•	•	•	•	•	•	•	•	•	•	•	X
	Piston pump	39	0 – 2.3 Lpm	•	X	X	•	•	•	X	•	•	X	X	X
	Centrifugal (low rate) pump	52	variable	•	•	•	•	•	•	•	•	•	•	•	•
Suction lift	Peristaltic pump	13	0.05 – 1.4 Lpm	•	X	X	•	•	•	X	•	X	X	X	•
Gas contact	Gas-lift pump	26	variable	X	X	X	X	X	X	X	X	X	X	X	X
	Gas-drive device	26	0.1 Lpm	•	X	X	•	X	•	X	•	X	X	X	X

Passive	Passive diffusion bag (may require different types to sample different analytes)	39	variable	X	X	X	X	•	X	X	•	•	X	X	X
	Discrete interval sampler	39	variable	•	•	•	•	•	•	•	•	•	•	•	•

1 It is assumed that existing monitoring bores are properly installed and constructed of materials suitable for detection of the parameters of interest.

2 Converted from imperial units to metric units.

3 Sample delivery rates and volumes are average ranges based on typical field conditions. Actual delivery rates are a function of the diameter of the monitoring bore, the size and capacity of the sampling device, hydrogeological conditions and the depth to sampling point. For all devices, delivery rate should be carefully controlled to prevent aeration or degassing of the sample.
• Indicates device is ***generally*** suitable for application (assuming device is cleaned and operated properly and is constructed of suitable materials).
X Indicates device may be unsuitable or is untested for application.

Source: Modified from US EPA (1992).

Appendix C: Field record sheets

<table>
<tr><td colspan="2">Site:</td><td colspan="2">Location:</td><td colspan="2">Date:
Weather:</td></tr>
<tr><td colspan="2">Person sampling:</td><td colspan="2">Sample device:</td><td colspan="2">Sampling location (depth):</td></tr>
<tr><td colspan="2">Pre-purging groundwater depth:</td><td colspan="2">Post-sampling groundwater depth:</td><td colspan="2">Flow cell: Yes/No</td></tr>
<tr><td colspan="2">Pump on (time):</td><td colspan="2">Sample no(s):</td><td colspan="2">Pump off (time):</td></tr>
<tr><td>Field meter calibration</td><td>EC:</td><td>pH:</td><td>DO:</td><td>Redox potential:</td><td>Temp:</td></tr>
</table>

Field measurements and stabilisation criteria

Time	Purge rate (mL/min)	Volume purged (L)	SWL (m)	Temp (°C)	Electrical conductivity (mS/cm)	pH	Redox (mV)	Dissolved oxygen (mg/L)